UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

PUMPAGE AND GROUND-WATER STORAGE DEPLETION IN CUYAMA VALLEY, CALIFORNIA, 1947-66

By

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Prepared in cooperation with the
Santa Barbara County Water Agency

OPEN-FILE REPORT

Menlo Park, California
August 3, 1970

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PUMPAGE AND GROUND-WATER STORAGE DEPLETION IN CUYAMA VALLEY CALIFORNIA, 1947-66

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ABSTRACT

Water-level declines of as much as 160 feet have occurred in the Cuyama Valley since 1947. The 1947-66 overdraft in excess of natural recharge is estimated at 21,000 acre-feet annually and is causing a water-level decline from 2 to 8 feet per year over an area of about 35,000 acres. For the period 1947-66 pumpage totaled about 1 million acre-feet, and ground-water storage depletion was more than 400,000 acre-feet.

Most of the ground-water body is unconfined, but ground-water movement is restricted by faults. About half of the 1966 natural ground-water recharge was used in the valley; the other half was lost by evapotranspiration, even though a substantial overdraft existed.

Ground-water quality is only fair for irrigation use and is gradually becoming worse as water from irrigated land returns to the water table.

In several areas of the valley imported water could be successfully recharged to the ground-water basin by spreading in recharge basins. Recharging might be most beneficial in T. 10 N., R. 25 W., where permeable deposits have a large unsaturated storage capacity.

INTRODUCTION

The present study of ground water in Cuyama Valley by the U.S. Geological Survey, in cooperation with the Santa Barbara County Water Agency, was started in February 1966. Its primary purpose was to delineate aquifers and to estimate storage changes, recharge, discharge, and pumpage. In addition, areas where artificial recharge of ground water could be accomplished were to be delineated, and the chemical quality of the ground water was to be evaluated.

The scope of the study included: (1) water-level measurements in about 250 wells, (2) inventory of new wells, (3) inventory of ground-water pumpage, (4) collection and chemical analysis of water samples, (5) drilling of small-diameter observation wells, and (6) compilation and analysis of all available geologic and hydrologic data.

The investigation was requested by the Santa Barbara County Water Agency to assist in determining the effects of large-scale agricultural development in the Cuyama Valley (fig. 1) during the past 20 years.

The only prior hydrologic investigation in the area was that of Upson and Worts (1951). Many geologic investigations have been made because of interest in oil field exploration and development. Some of the geologic studies that are also pertinent to the hydrology of the area are those of English (1916), Eaton (1939), Schwade (1954), Hill, Carlson, and Dibblee (1958), Vedder and Repenning (1965), Vedder (1968), and many unpublished maps.

The present investigation was carried out by the U.S. Geological Survey, Water Resources Division, under the general direction of R. Stanley Lord, chief of the California district, and under the immediate supervision of L. C. Dutcher, chief of the Garden Grove subdistrict.

Cuyama Valley is about 35 miles north of Santa Barbara in the southern part of the Coast Ranges of California (fig. 1). The study area is enclosed by the drainage divides along the crest of the Caliente Range on the north, the crest of the Sierra Madre Mountains on the south, and the crest of a series of low hills between the Cuyama Valley and the San Joaquin Valley to the northeast. The western boundary of the valley is the canyon reach just west of the confluence of the creek in Cottonwood Canyon and the Cuyama River. Hence, the whole drainage area of the Cuyama River upstream from Cottonwood Canyon is the study area and encompasses about 690 square miles in parts of Santa Barbara, San Luis Obispo, Ventura, and Kern Counties.

Altitudes within this area range from about 1,600 feet above sea level at the western boundary to more than 8,000 feet in the headwaters of the Cuyama River. Within the central part of the Cuyama Valley, herein defined as that part of the study area where the alluvial plain is 4 to 6 miles wide lying mainly in T. 10 N., Rs. 25 and 26 W., the altitude ranges from about 2,000 to 2,600 feet.

The semiarid climate of Cuyama Valley is characterized by hot, dry summers and cold winters. Rainfall occurs mostly during the winter and spring and totals less than 6 inches per year at Cuyama and 12 to 14 inches per year on the lower slopes of the surrounding mountains, as represented by the station at Ozena (fig. 2). Greater precipitation, about 24 to 30 inches per year, occurs in the mountainous headwaters of the Cuyama River and along the crest of the Sierra Madre Mountains (fig. 3).

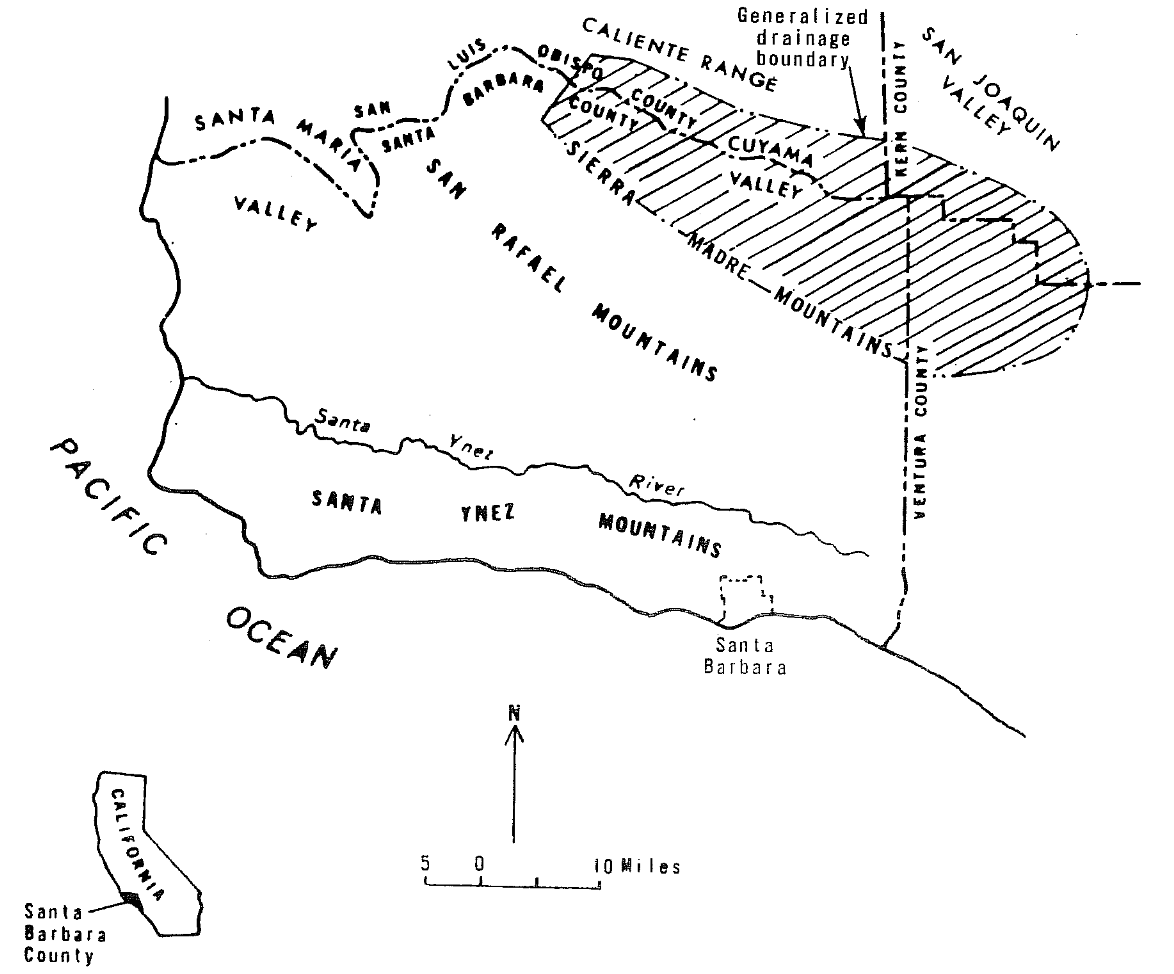


FIGURE 1.--Index map.

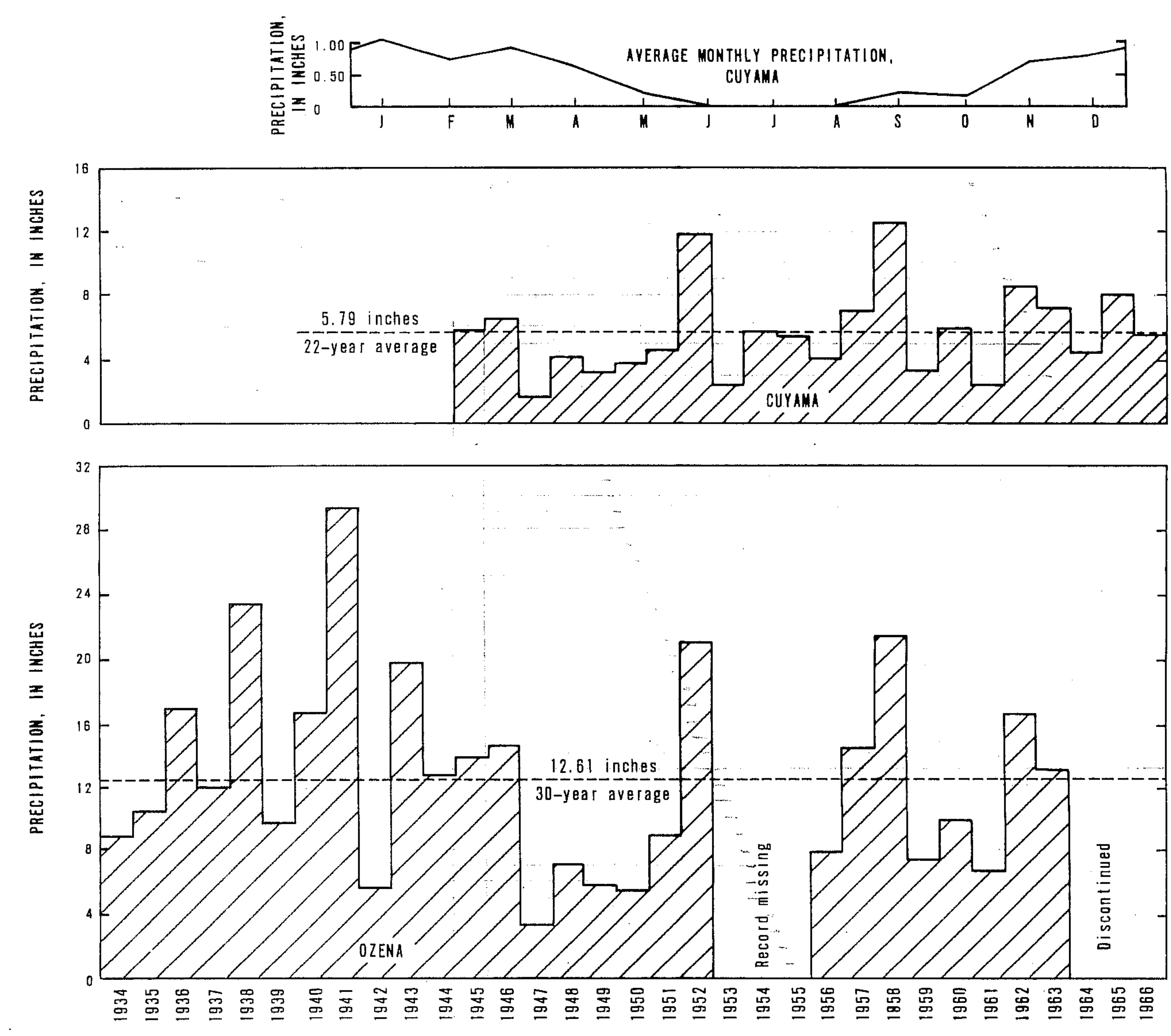


FIGURE 2.--Average annual precipitation at Ozena and Cuyama.

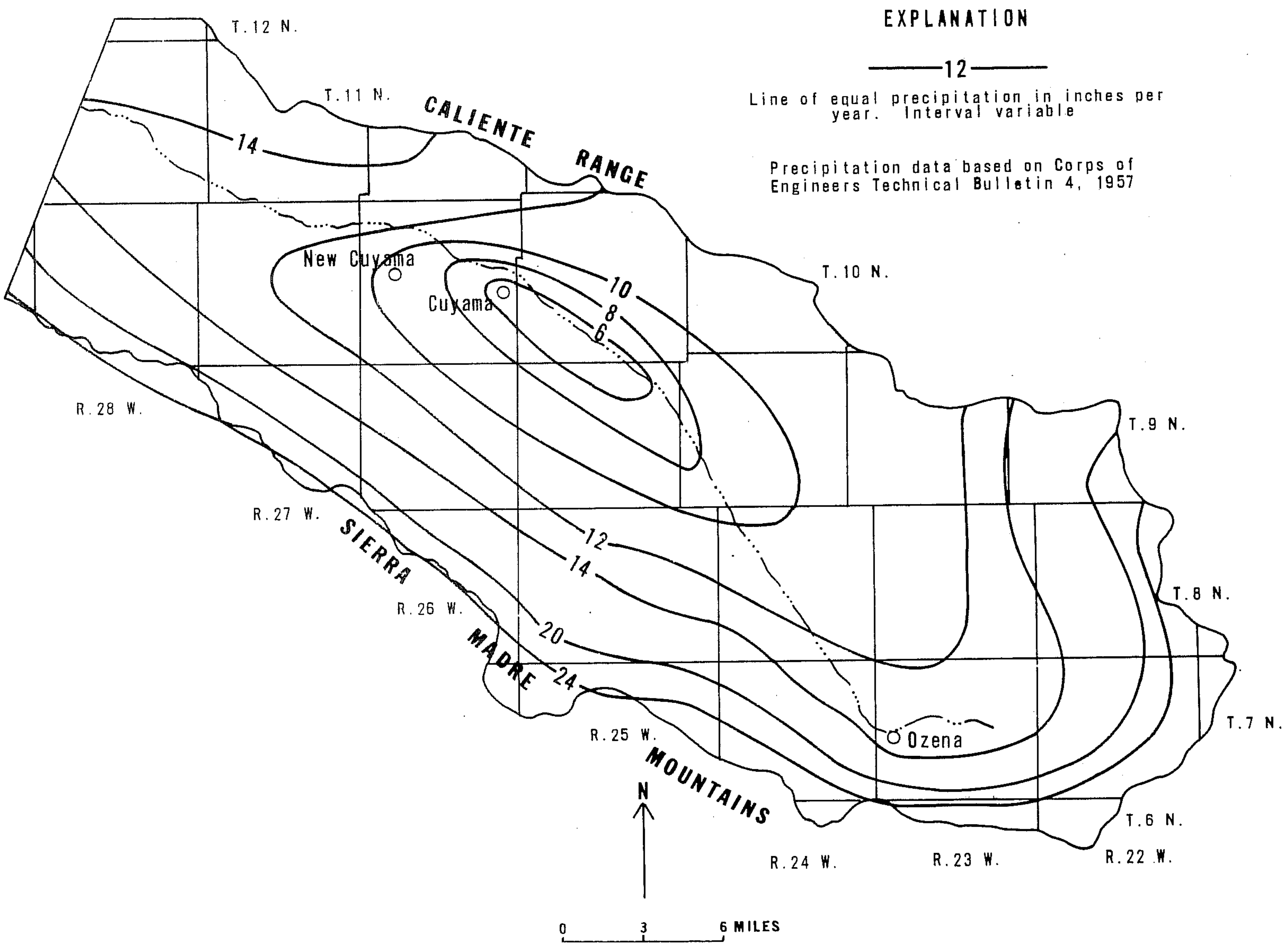
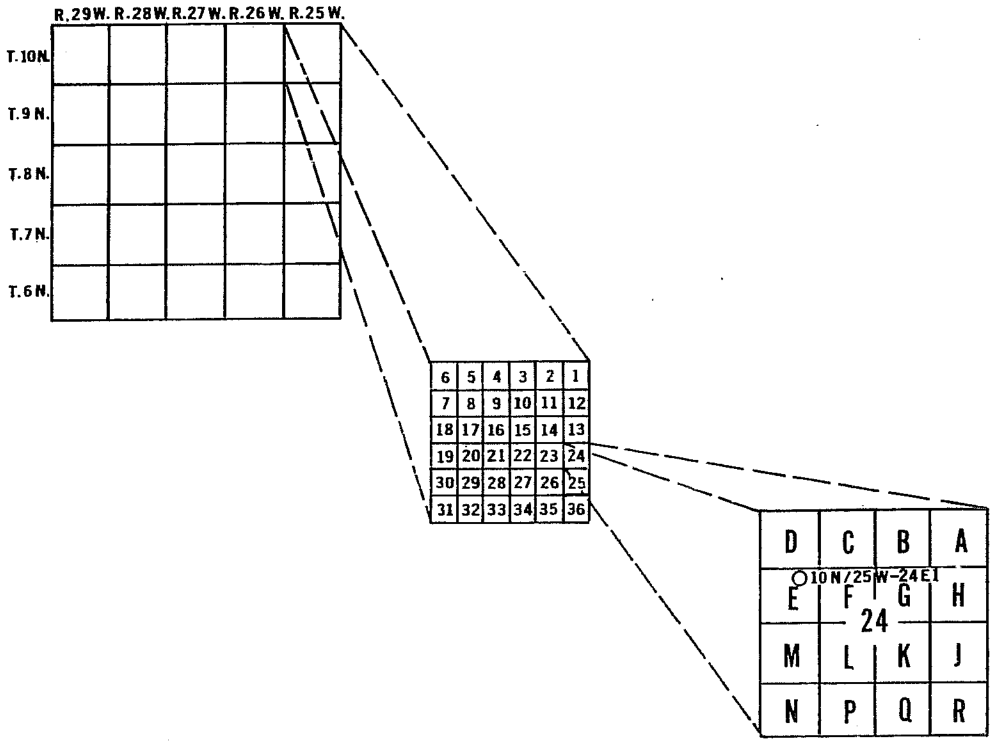


FIGURE 3.--Isohyetal map of Cuyama Valley.

WELL-NUMBERING SYSTEM

Wells within the area are numbered according to their location in the rectangular system for the subdivision of public land. For example, in the number for well 10N/25W-24E1 shown in the diagram that part of the number preceding the slash indicates the township (T. 10 N.); the number and letter following the slash indicate the range (R. 25 W.); the number following the hyphen indicates the section (sec. 24); the letter following the section number indicates the 40-acre subdivision of the section according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. The area covered by this report lies in the northwest quadrant of the San Bernardino base line and meridian.

Springs are numbered similarly except that an S is placed between the 40-acre subdivision letter and the final digit as shown in the following spring number: 10N/27W-6AS1.



SUMMARY OF GEOLOGY

Structure

Cuyama Valley was formed by a downfaulted block of the earth's crust called a graben. This block is bordered on the north by the Morales and Whiterock faults and on the south by the South Cuyama and Ozena faults. Along these borders the faults have thrust older rocks of pre-Pliocene age over the rocks of Pliocene age and younger (fig. 4). Maximum displacement along the north-bordering faults is about 15,000 feet and along the south-bordering faults about 10,000 feet (Schwade, 1954). In the eastern part of the valley the north-bordering faults approach the San Andreas fault zone and the south-bordering faults approach the Big Pine fault.

The geologic structure of the graben area is known mainly from results of oil exploration. The eastern part of the central valley area is underlain by a large syncline, the axis of which strikes roughly parallel to the elongation of the valley and plunges towards the northwest. The steep northeastern limb of this syncline terminates against the Morales fault.

Near the western boundary of the area, an anticline in rocks of pre-Pliocene age is exposed. Two oil fields are associated with this structure. In the eastern part of the study area the beds are tightly folded and deformed. The dominant structural trend of the folds is parallel to the San Andreas fault zone.

Faults in the alluvium along Graveyard and Turkey Trap Ridges and at the mouth of Santa Barbara Canyon appear to affect the movement of ground water (fig. 4). Much of the evidence for postulating the positions of Graveyard and Turkey Trap faults, as shown in figure 4, is discussed by Upson and Worts (1951). Additional hydrologic evidence for the location of these faults is discussed in a following section of this report.

Stratigraphy

Sedimentary deposits in the Cuyama Valley area range in age from Cretaceous to Holocene; igneous rocks of Jurassic(?) age form the basement complex. Deposition of marine beds, now indurated to sandstone and shale, predominated in the area until Miocene time when the sea began to retreat and fluvial deposits, now claystone, sandstone, and conglomerate, were laid down. The fluvial rocks in the eastern part of the area grade into and interfinger with marine rocks to the west. Pliocene time was marked by the complete withdrawal of the sea from the area and the deposition of the clay, silt, sand, and gravel of the Morales Formation. The basement complex and all sedimentary rocks older than the Morales Formation are grouped as non-water-bearing rocks on the geologic map (fig. 4).

The Morales Formation is present throughout the valley and rests unconformably on the more consolidated older rocks. Its lateral extent is generally limited by thrust faults. The formation attains a maximum thickness of about 10,000 feet along the northern margin.

Pliocene and Pleistocene(?) time was marked by the deposition of the Paso Robles Formation, in the eastern part of the study area. This now dissected fanglomerate is grouped with the non-water-bearing rocks on the geologic map because of its limited thickness and position above the water table.

The deposits of Pleistocene and Holocene age shown on the geologic map as younger and older alluvium, respectively, consist of sand, gravel, and boulders with some clay. The clay content of both these units increases towards the west, and some of the clay is of possible lacustrine origin. The contact between the younger and older alluvium cannot be readily distinguished in drilling records but usually can be identified in outcrops and by the topographic relation of the units. These deposits range in thickness from 5 to 50 feet in the western part of the area to possibly as much as 1,100 feet in T. 10 N., R. 25 W.

HYDROLOGY

Aquifer Units and Extent

As mentioned, all rocks that are older than the Morales Formation generally are considered either to be non-water-bearing or to contain water of unusable quality for domestic and irrigation uses. Most of these rocks are consolidated claystone, shale, and sandstone, which, in the central part of the valley, occur only at great depth (fig. 4). Some localized zones of usable water do occur in these rocks, largely in the upper parts, as indicated by data from a few small wells which generally yield less than 5 gpm (gallons per minute).

Permeabilities in the water-bearing Morales Formation vary greatly both laterally and with depth. The highest values occur in the syncline beneath the central part of the valley and become increasingly lower to the west. The formation is coarse grained and probably moderately permeable in the eastern and southeastern parts of the valley where it crops out, but here the land is topographically unsuited to agricultural development.

Numerous wells with low to moderate yields tap the Morales Formation in the western one-third of the study area, and specific capacities range from about 5 to 25 gpm per foot. Specific capacity is defined as the yield of the well, in gallons per minute, divided by the pumping drawdown, in feet. Wells with high yields in the central part of the valley tap the younger and older alluvium as well as the Morales; hence aquifer characteristics must be inferred from a few oil-well electric logs. These suggest a saturated thickness of more than 1,000 feet along the northern margin of the central valley. Correlating electric logs in this area with wells having electric logs and pump-test data, an average specific capacity of from 25-50 gpm per foot is estimated for wells drilled into the more permeable part of the formation.

Most of the water pumped in the study area is contained in the younger and older alluviums, and because they are indistinguishable in the subsurface, they hydrologically constitute one unit. The highest permeabilities are north of the Cuyama River in T. 10 N., Rs. 25 and 26 W. Farther west, in T. 10 N., R. 27 W., the silt and clay content increases with a corresponding decrease in permeability. Many large-capacity wells perforated in the alluvium yield 1,000-3,000 gpm, and specific capacities range from 100 to more than 200 gpm per foot. Pumping from the alluvium also occurs in the eastern part of Cuyama Valley, along Cuyama River and its tributary canyons as far as a few miles upstream from Ozena.

Ground-Water Movement

The regional flow pattern of ground water under natural conditions was northwestward, down the valley, with a substantial component of flow northward from the Sierra Madre Mountains. After 20 years of substantial pumping the water-level contours for 1966 (fig. 5) indicate the same general flow pattern; however, a pumping depression has developed in T. 10 N., R. 25 W., as shown by the 2,140-foot water-level contour.

The effect on water levels of faults along Graveyard and Turkey Trap Ridges as postulated from ground-water data by Upson and Worts (1951, p. 43) appears to be considerably greater in 1966 than in 1947. Although many of the springs and seeps that flowed in 1946 have dried up in recent years, the 1966 water-level data show a 120-foot drop across the eastern part of Turkey Trap Ridge and an 80-foot drop across the western part of Graveyard Ridge. Wells that tap the block contained between the two faults sustain a large pumpage, and because the faults retard the movement of water to this block, the resulting water-level decline is great. The wells are perforated in the same general stratigraphic range as other wells in that area, and hence the possibility of their tapping a deeper or shallower aquifer than the other wells is not likely. Similar water levels in wells 10N/26W-9P1, 9R3, and 15B1, in the narrow block, indicate a steep cone of depression.
Well 10N/26W-9J1, only about 1,000 feet north of the fault block, has a water

level 80 feet higher. Because the two faults do not intersect land surface, their location is inferred from well data and topographic features. Whereas Upson and Worts (1951) postulated the relative movement of these faults to be up on the north, electric logs of exploratory oil wells indicate that the south side is uplifted in relation to the north.

Water levels are offset 110 feet across a fault near the mouth of Santa Barbara Canyon (fig. 5). In 1966 well 9N/25W-12R1 had a water-level elevation of 2,462 feet, whereas well 9N/25W-13B1, only about 1,500 feet away, had a water-level elevation of 2,572 feet, a difference of 110 feet. This water-level offset had existed throughout the period of record, as substantiated by Upson and Worts (1951, p. 48). Also, records show little water-level decline over the years at well 9N/25W-13R1, whereas water levels in wells immediately downstream have declined greatly and some wells are now dry. Although Upson and Worts attributed this steep hydraulic gradient to changes in permeability combined with a change in cross-sectional area, the present data suggest that it is caused by a fault which may be an extension of a fault mapped by Dibblee and Wagner (written commun., T. W. Dibblee, Jr., 1966, and H. C. Wagner, 1968) in secs. 9 and 10, T. 9 N., R. 25 W. (fig. 5).

Water-Level Decline, 1947-66

Typical water-level fluctuations in the valley are illustrated by the hydrographs in figure 6, which are indicative of water-level fluctuations in their respective areas. They show the long-term trends and response to precipitation and recharge, and pumping and discharge. Wells 8N/24W-8L1 and 9N/24W-33M1 in the upper part of the valley show little water-level decline over the period of record and indicate that at the current pumping rate upstream from Santa Barbara Canyon, recharge from the Cuyama River is sufficient to maintain the ground-water level. The hydrographs also show response to precipitation and recharge as indicated by above-average precipitation in 1958.

At the lower end of the valley well 10N/27W-12R1 shows the overall downward trend of the water level caused by ground-water storage depletion resulting from increased ground-water pumping upstream. Well 10N/26W-22A1, 3-1/2 miles upstream from well 10N/27W-12R1, has similar water-level fluctuations. Well 10N/25W-24E1 is on the eastern edge of the cone of depression caused by concentrated pumping for agriculture in T. 10 N., R. 25 W., and indicates a steady and increasingly steeper downward trend in the water level. This downward trend indicates that a nonequilibrium condition exists caused by pumpage exceeding the ground-water inflow to this area. The fault immediately north of the well is effective in preventing or impeding recharge from the north. The pumping hole now intercepts recharge from the Cuyama River. Figure 7 shows the net water-level decline for the period 1947-66.

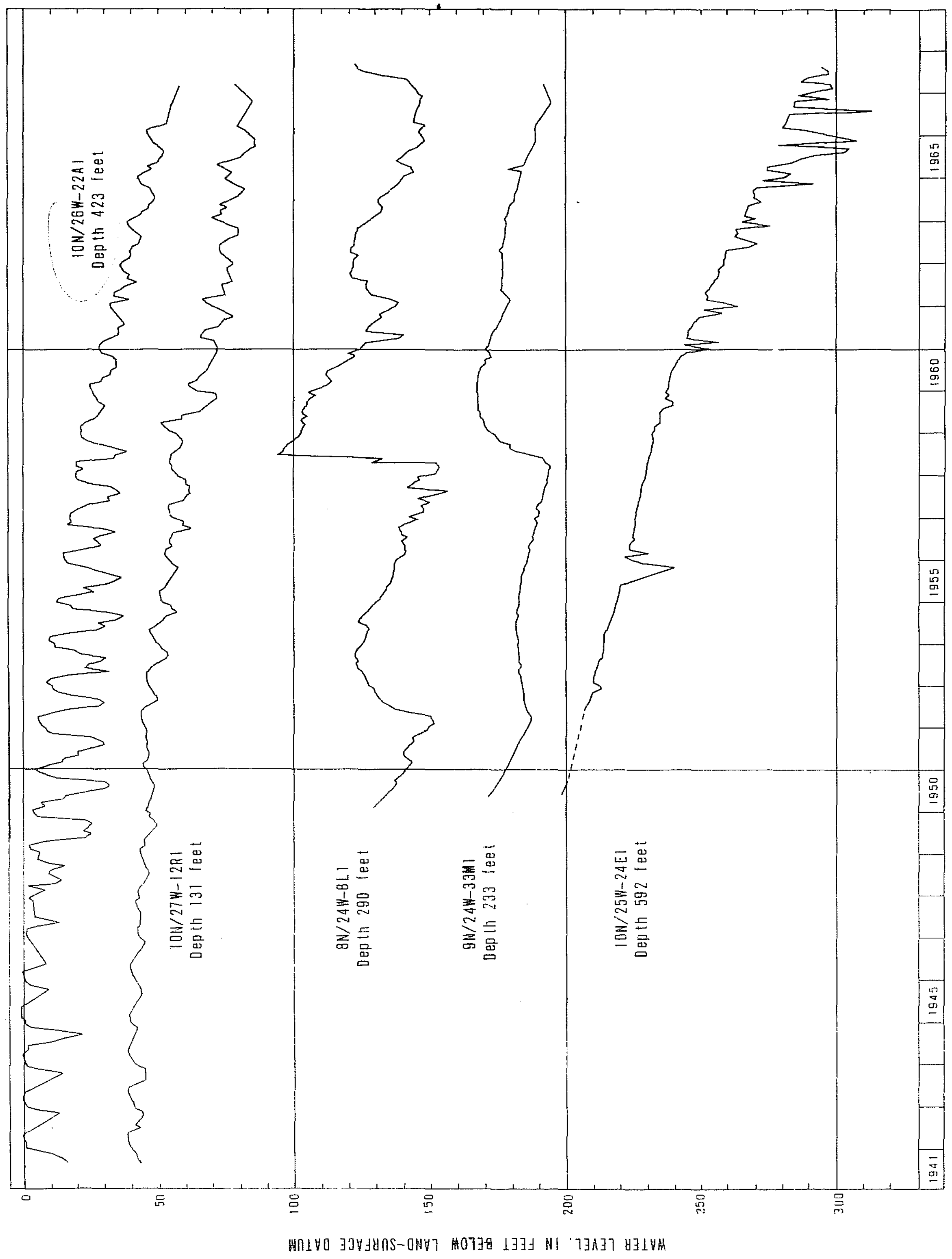


FIGURE 6.--Hydrographs of five wells in Cuyama Valley.

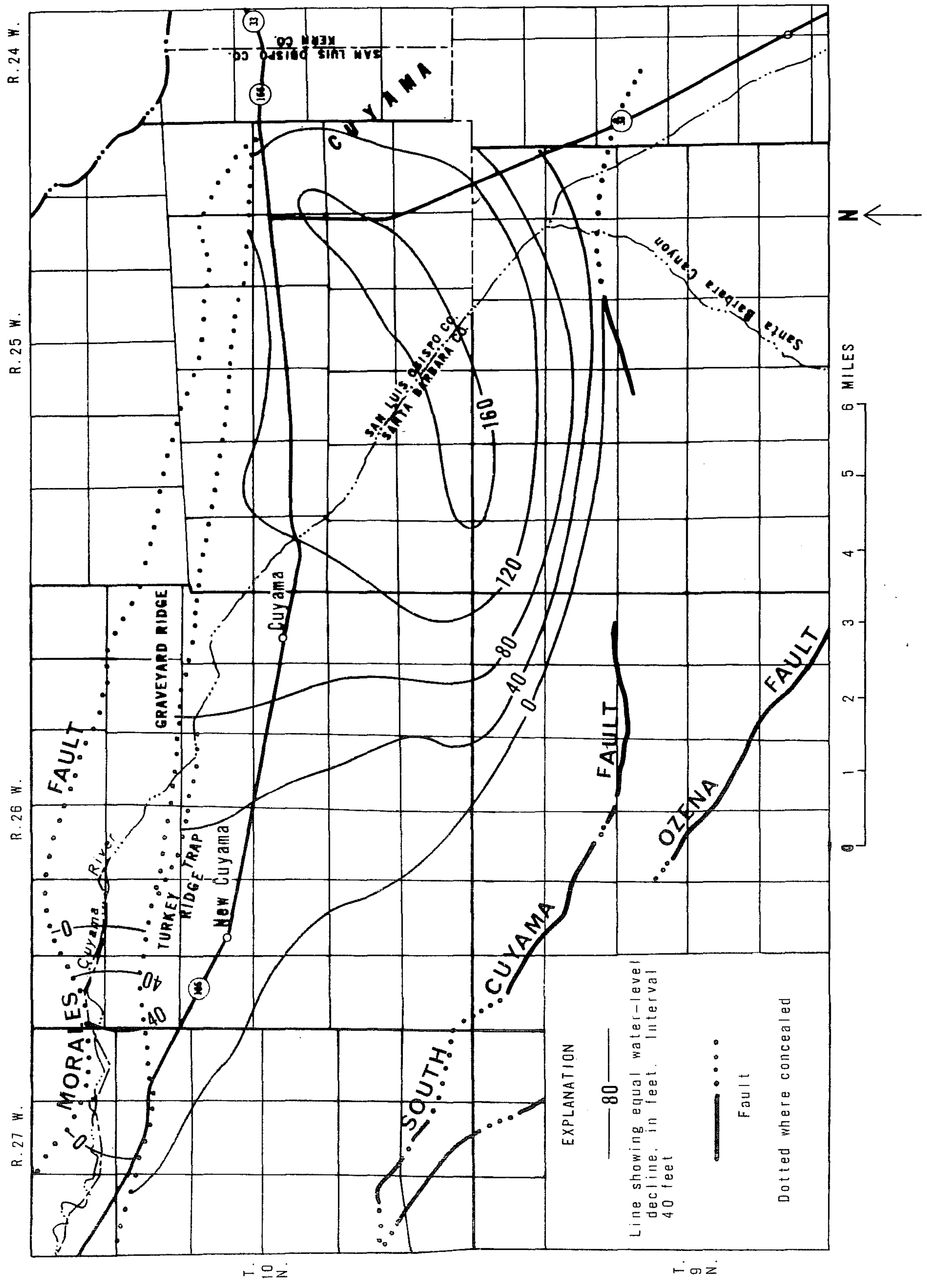


FIGURE 7.--Water-level decline, 1947-66.

The major pumping depression centers beneath T. 10 N., R. 25 W. The deepest part is defined by the closed 2,140-foot water-level contour (fig. 5) and reflects a water-level decline of more than 160 feet since 1947 (fig. 7). The depression extends up the valley as far as well 9N/25W-12R1, in an area where pumping is rather limited, southward nearly to the South Cuyama fault, and westward some 3 miles beyond New Cuyama. The northern edge of the pumping depression may be truncated by Turkey Trap and Graveyard faults.

Ground water within Cuyama Valley is mostly unconfined and generally consists vertically of a single water body. As already mentioned, Turkey Trap and Graveyard faults act as barriers to ground-water flow, thereby dividing the water body laterally into several segments. Local areas of confinement and perched water do exist, however. For example, in 1968 falling water was noted in some wells in T. 10 N., R. 26 W., and probably is a result of water-level declines lowering the water levels below sand lenses that are now draining through the perforations into the well. Drillers have reported occasional rises in water levels during drilling operations. Shallow domestic wells south of Highway 166 in T. 10 N., R. 26 W., tap an extensive body of perched water.

For the above-mentioned reasons, the water-level contours in figure 5 were drawn on the water body contained in the younger and older alluviums and ignore local perched water. Contours are long dashed in the area underlain by the Morales Formation where the control is poor. No wells tap this unit in the badlands area on the east; therefore, no contours were drawn southeast of Santa Barbara Canyon except in the alluvial fill.

The contours also reflect the general difference in transmissivity between the alluvium and the Morales Formation. Gradients within the Morales Formation west of New Cuyama are steeper than those within the alluvium and steepen toward the west where the transmissivity is less. Except in the pumping depression, where the gradient is very low, and immediately downstream from the fault at Santa Barbara Canyon, where ground water is spilling across the fault and into the pumping depression, gradients within the alluvium are fairly uniform.

HYDROLOGIC BUDGET

Total Runoff

Direct precipitation is the only source of recharge water within the study area. Precipitation ranges from 6 to more than 24 inches annually. In the central and lower parts of Cuyama Valley, average annual rainfall is 6-12 inches (fig. 3). Since the early 1940's, there have been only 3 years--1952, 1958, and 1962--when precipitation exceeded 8 inches at Cuyama and 16 inches at Ozena (fig. 2). The Caliente Range generally receives less than 14 inches annually.

The area of greatest average annual precipitation, and consequently the largest source of water, is the highlands in the southeastern half of the study area. Runoff from the Sierra Madre Mountains is also substantial and is an important source of water to the central and lower parts of the valley.

Runoff from the mountains normally sustains flow in the Cuyama River upstream from Ventucopa. At a stream-gaging station near Ozena (fig. 4), maintained by the U.S. Geological Survey during the period 1944-58, the average annual streamflow was about 5,500 acre-feet from a drainage area of 90 square miles. In 1952 and 1958 runoff was 14,500 and 26,200 acre-feet, respectively. The long-term average annual runoff was estimated by rainfall-runoff relations to be 7,500 acre-feet for the station (written commun., S. E. Rantz).

Although no measurements of the total long-term average runoff within the study area are available, total runoff was estimated by using rainfall-runoff relations. The total long-term average annual runoff originating within the entire 690-square-mile study area and available for recharge to the alluviums and Morales Formation is about 22,000 acre-feet (written commun., S. E. Rantz).

For the 20-year period 1947-66, the rainfall was 90 percent of normal; this value was used to adjust the long-term average runoff to estimate the 1947-66 runoff. For the 8-year period 1939-46, the rainfall was 118 percent of normal; the estimated runoff for that period was also adjusted. For all years prior to 1939, a steady-state condition was assumed, and the long-term average runoff of 22,000 acre-feet per year was used.

Natural Surface-Water Outflow

The surface-water outflow from the study area is measured where Cuyama River crosses the western boundary. The natural surface-water outflow consists of two components: (1) base flow, which is discharging ground water, and (2) floodflow. Although at the beginning of the study a stream-gaging station was installed at this site, the records are not of sufficient length for estimating long-term outflow. In an independent study, E. R. Hedman (written commun., 1969), using data from a survey of the channel geometry, calculated that the long-term mean runoff for Cuyama River below Cottonwood Canyon was about 12,000 acre-feet per year. This includes both base flow and floodflow. From previous estimates by Upson and Worts (1951, p. 54), the base flow probably averaged about 3,000 acre-feet per year under natural conditions. Hence, the long-term natural outflow from the study area probably was about 3,000 acre-feet per year base flow and 9,000 acre-feet per year floodflow. Here again the long-term average annual outflow is used for the pre-1939 period and is adjusted for the wet 1939-46 and dry 1947-66 periods.

Ground-Water Recharge and Natural Discharge

A substantial part of the natural runoff to the valley provides recharge to the ground-water reservoir. Beginning a few miles downstream from Ozena, streamflow infiltrates the coarse-grained deposits of the Cuyama River. Consequently, the central 25-mile reach of the river is dry, except during times of flood. The depth to the water table ranges from a few feet to more than 300 feet below land surface in this reach.

In the central and lower parts of Cuyama Valley, drainage from the northern slopes of the Sierra Madre Mountains provides recharge to the water table in the Morales Formation and in the alluvial deposits. Ground-water recharge derived from the infrequent runoff from the Caliente Range probably is minor.

The long-term annual gross recharge to the alluviums and Morales Formation was obtained by subtracting the long-term annual flood outflow from the long-term annual runoff. Hence 22,000 acre-feet per year minus 9,000 acre-feet per year results in a long-term potential recharge of about 13,000 acre-feet per year. For the wet period 1939-46, the gross average recharge was about 16,000 acre-feet per year, and for the drier 1947-66 period the recharge was about 12,000 acre-feet per year, assuming that (1) the period 1939-46 had precipitation of 118 percent of normal, (2) the period 1947-66 had precipitation of 90 percent of normal, and (3) precipitation is a direct index of runoff and recharge to ground water. Direct recharge from precipitation was small because rainfall on the permeable valley floor and fans is generally less than 12 inches.

In Cuyama Valley ground water is discharged by springs, evapotranspiration, effluent seepage to the river, pumpage, and by underflow in the permeable deposits at the lower end of the valley. Before large-scale pumping began in 1939, the largest water losses were by evapotranspiration from areas of nonbeneficial vegetation. Upson and Worts (1951, p. 53) estimated these losses at 8,000 acre-feet per year. Although in a few small areas seeps and springs have ceased to flow in recent years, and in other areas the water table had declined greatly, water use by phreatophytes has not been greatly reduced. Dense stands of brush, willow, and grass still exist near and downstream from Turkey Trap Ridge. Thus, in 1966, the estimated losses due to evapotranspiration from about 2,000 acres were 6,000 acre-feet per year.

On the northern slopes of the Sierra Madre Mountains and in the badlands of the upper Cuyama Valley a few minor seeps and springs occur other than those near the river in the lower part of the valley. In general, the springs yield only a few gallons per minute. A series of springs in the central part of the valley and along the terrace front south of State Highway 166 in T. 10 N., R. 27 W., had a combined discharge of about 2,600 acre-feet per year in 1947 (Upson and Worts, 1951, p. 52 and pl. 5). Many of those springs are now dry. A notable exception is spring 10N/27W-6AS1, which flowed at the rate of about 200 gpm throughout most of 1966 and 1967.

Most water from springs is either lost by evapotranspiration or ultimately reaches the Cuyama River by underflow or surface flow and is accounted for in the total estimates of discharge from the study area.

As previously stated, effluent seepage from ground water, which occurs as base flow in the river leaving the study area, was estimated to be 3,000 acre-feet per year prior to the advent of large-scale pumping. Current data indicate that base flow has been reduced to nearly zero. Nowhere is the water table now at the ground surface, except temporarily during floodflow, after which it rapidly declines.

Ground-water outflow in 1947 was estimated to be 2,500 acre-feet per year by Upson and Worts (1951, p. 56). The cross-sectional area where they computed outflow was secs. 1 and 12, T. 10 N, R. 27 W. Calculation of the outflow for 1966 was made along the same section selected by Upson and Worts, using the same values of permeability but reducing the thickness of saturated section to 80 feet. The thickness of the section was reduced because of the water-level decline that has occurred in that area between 1947 and 1966. The gradient along the section in 1947 was 60 feet per mile with the component at right angles to the section being 35 feet per mile. In 1966 the gradient along the section was 25 feet per mile with the component at right angles to the section being 15 feet per mile. On this basis, the calculated 1966 underflow was 1,100 acre-feet per year. However, most of this estimated underflow is used by phreatophytes in the area between this cross section and the western boundary of the present study area.

The water-level contours (fig. 5) indicate that most of the water in the Morales Formation is moving toward the alluvium. At the western boundary of the study area the alluvium is almost completely unsaturated. Hence, about 500 acre-feet is considered to be the underflow leaving the study area in 1966.

Pumpage

During the 20-year period 1947-66, gross pumpage in Cuyama Valley was about 1 million acre-feet, based on calculations of power consumed and pump efficiencies, or an average of about 52,000 acre-feet per year. During the 8-year period 1939-46, when significant pumping for irrigation first occurred in the valley, gross pumpage was estimated by Upson and Worts (1951, p. 51) to be 87,600 acre-feet, or an average of about 11,000 acre-feet per year. On the basis of (1) the permeable nature of the soil and substrata in the central part of the valley, which is the center of agricultural development, (2) the type of application (50 percent flood irrigation), (3) the high dissolved-solids content of the ground water, and (4) recent figures for consumptive use by various crops (2.8 feet per year as an average for all crops, with rainfall taken into account (U.S. Bureau of Reclamation, 1967)), the authors have assumed that the applied irrigation water returned to ground water is about 50 percent. Thus, annual consumptive use of ground water has been at the average rate of about 26,000 acre-feet during the 20-year period 1947-66. Table 1 shows the estimated gross agricultural pumpage for Cuyama Valley, 1947-66.

An additional 1,000 acre-feet is probably pumped annually to meet the demands of the petroleum industry and of public supply in the valley.

The increase in agricultural pumpage in Cuyama Valley is due not only to the expansion of the irrigated acreage but also to a change in crop patterns. Whereas potatoes and grains were the principal crops in the early 1940's, alfalfa has been the principal crop in recent years. The water use by alfalfa, which is grown on more than half the irrigated acreage in the valley and yields an average of five cuttings per year, is considerably higher than that of most other crops. Changes in crop patterns are reflected in table 2.

TABLE 1.--*Estimated gross agricultural pumpage, 1947-66*

Year	Pumpage in acre-feet	Year	Pumpage in acre-feet
1947	21,300	1957	47,900
1948	31,300	1958	47,600
1949	33,700	1959	57,000
1950	48,000	1960	57,300
1951	46,000	1961	58,200
1952	60,400	1962	66,800
1953	48,100	1963	67,100
1954	56,600	1964	60,900
1955	61,600	1965	57,000
1956	56,700	1966	57,300
Total (rounded):			1,000,000
Annual average:			52,000

TABLE 2.--*Irrigated acreage*

Crop	Total irrigated acres[1]					
	1939	1941	1946	1952	1959	1966
Alfalfa	-	-	60	-	6,334	5,400
Irrigated pasture	-	-	-	-	1,157	1,815
Truck crops, incl. potatoes	400	4,596	3,507	-	594	1,950
Field crops, incl. sugar beets and corn	-	-	-	-	763	513
Grain and hay	-	-	1,500	-	109	485
Deciduous orchard	-	-	-	-	35	320
Citrus	-	-	-	-	17	17
Total	400	4,596	5,067	a9,895	9,009	10,500

[1] Data from Upson and Worts (1951, table 3); State of California, Department of Water Resources; Santa Barbara County Water Agency, Land Use Survey 1966; and field observations by the junior author.

a. Written communication, R. M. Waller.

Water Yield and Overdraft

Before 1939 the ground-water basin was in a state of equilibrium; that is, over the long term ground-water discharge equaled ground-water recharge and aquifer-storage change was nearly zero, because of almost no pumping. During the wet period 1939-46, the situation did not change significantly, and most of the ground water being pumped from storage at that time was replenished by above-average recharge. Current ground-water withdrawals are taken in part from salvaged discharge as follows: 2,000 acre-feet annually from the reduced ground-water outflow, 3,000 acre-feet from reduced ground-water effluent seepage to the river at the west end of the study area (baseflow), and 2,000 acre-feet from reduced evapotranspiration; hence, a net yield of 7,000 acre-feet annually. If net pumpage continues at a rate of about 31,000 acre-feet per year (1962-66), at least 24,000 acre-feet will have to continue to be made up from ground-water storage annually, unless more of the natural water losses can be salvaged.

The perennial yield of the basin of course is limited to the long-term average runoff to the area, an estimated 22,000 acre-feet per year. However, to achieve this figure would necessitate the salvage of all natural water losses, including the building of surface reservoirs to retain the floodflow for later release and recharge. The retention of virtually all water, combined with the recycling of ground water for irrigation use, would ultimately cause an adverse salt balance within the ground-water basin.

As shown in table 3, the estimated deficit during the period 1947-66 averaged about 21,000 acre-feet per year. However, a substantial quantity of natural discharge also was occurring during that period.

The previously discussed hydrologic estimates are summarized in table 3.

TABLE 3.--*Water budget*

(acre-feet per year)

	Natural conditions	1939-46	1947-66
Average inflow	+22,000	+26,000	+20,000
Average floodflow out of study area	- 9,000	-10,000	- 8,000
Average ground-water recharge	+13,000	+16,000	+12,000
Ground-water discharge			
Evapotranspiration	- 8,000	- 8,000	- 6,000
Underflow from study area	- 2,500	- 2,500	- 500
Base flow out	- 3,000	- 3,000	0
Pumpage (net)	0	- 5,000	a-27,000
Total (rounded)	-13,000	-18,000	-33,000
Balance (average change in storage)	0	- 2,000	-21,000

a. Includes 26,000 acre-feet estimated agricultural use plus 1,000 acre-feet estimated for industry and public supply.

More realistically, the salvage of water currently being lost by evapotranspiration would be more easily achieved. With the judicious spacing of new wells, the water table would be lowered and nearly all evapotranspiration eliminated. Some additional recharge might be induced if the water table in the western third of the study area were lowered. However, because of the flash floodflows in this area, and the lower permeability of the sediments, in relation to those in T. 10 N., R. 25 W., recharge induced by lowering water levels in the western part of the valley probably would be small.

Depletion of Ground Water in Storage, 1947-66

The estimated storage depletion during the 20-year period 1947-66 was the annual storage depletion times years or: total storage depletion equals 21,000 acre-feet per year (table 3) times 20 years or 420,000 acre-feet. Because the methods of deriving estimates of gross pumpage, consumptive use of irrigation water, and salvaged natural discharge are subject to error, the estimated total net storage depletion during the period 1947-66 is computed directly to compare the results obtained by the two methods.

Depletion of storage in the ground-water reservoir since 1947 has caused a water-level decline of from 2 to 8 feet per year in an area of about 35,000 acres; this storage depletion is continuing at the present time. Calculations, using the water-level change map for the period 1947-66 (fig. 7), suggest that a volume of about 3 million acre-feet of deposits had been dewatered.

Static water levels were as much as 350 feet below land surface in 1966, and the water levels are declining. This trend probably will continue at an increased rate in the future, as the existing cone of depression expands into areas where the alluvial deposits have a lower permeability or intercepts fault boundaries. Also to be considered is the fact that much of the water remaining in storage is contained in the fine-grained Morales Formation which may have a specific yield less than that of the alluvium.

On the basis of data from drillers' logs of wells, and using specific-yield values assigned to several classifications of alluvial materials determined by Johnson (1967), an average specific yield of 15 percent for the dewatered alluvial materials in Cuyama Valley appears reasonable. If an average specific yield of 15 percent is used for the dewatered alluvial deposits, the computed change of ground water in storage during the period 1947-66, is:

Change in storage = 3,000,000 x 0.15 = 450,000 acre-feet.

Thus, the estimated storage depletion, using the available water level and specific yield data, agrees within 10 percent with the estimates of ground-water storage depletion of 420,000 acre-feet derived by the water-budget method outlined previously.

CHEMICAL QUALITY OF GROUND WATER

Ground water in the central part of Cuyama Valley commonly contains from 1,500 to 1,800 mg/l (milligrams per liter) of dissolved solids. The water ranges from hard to very hard and is predominately of the calcium-magnesium sulfate type, with calcium plus magnesium and sulfate accounting for 75 to 85 percent of the total cations and anions, respectively. Beneath the peripheral part of the valley the water quality is variable. In semiperched aquifers the quality of the water reflects the recharge from springs and the runoff from the Sierra Madre Mountains. The dissolved-solids content of water from wells and springs in the northern and northeastern parts of T. 10 N., R. 28 W., and in some canyons of the eastern badlands, is only 400 to 700 mg/l, and most of the water is of the sodium or calcium bicarbonate type.

Water of inferior quality, containing from 3,000 to more than 6,000 mg/l of dissolved solids, is pumped from some wells close to the Caliente Range and from wells in the extreme northeastern part of the valley. This water quality presumably results from the mixing of water from the marine rocks of Miocene age with the more typical water from the alluvium and is characterized by increased sodium, chloride, and boron. Although chloride and boron concentrations commonly are less than 30 and 0.20 mg/l, respectively, in the central part of the valley, the water from many wells close to the Caliente Range contains several hundred to nearly 1,000 mg/l of chloride and as much as 15 mg/l of boron.

Two wells in the western part of the study area that tap only marine rocks produce brackish water which is used as a source of salt water for injecting into the reservoir rock at the oil fields.

Some information from electric logs of oil wells indicates that water of acceptable quality extends to depths greater than 1,000 feet in parts of the valley and, locally, water in some deep aquifers is somewhat less mineralized than water from shallower aquifers.

Although ground water in Cuyama Valley is only of fair chemical quality, it has been used successfully to irrigate most crops. Presumably this has been possible because the sodium content of most of the water is relatively low and the soils are generally quite permeable. However, degradation of water quality in the principal area of agricultural development is taking place in two ways: (1) Ground-water gradients favor the movement of brackish water from north of the Cuyama River toward areas of heavy withdrawals; and (2) the return of some water applied during irrigation and needed for leaching the soil carries dissolved salts with it to the water table. This form of recharge has resulted in transporting accumulated salts from the root zone to the water table. Both processes lead to an increase in the dissolved solids in the main ground-water body.

Some wells in marginal areas are unused because of increasing salinity of the water; others have been replaced by deeper wells. Deterioration of water quality as the result of the recycling of leaching irrigation waters is especially manifested by the increasing nitrate concentrations, which have exceeded 400 mg/l in some shallow wells. The nitrates presumably are derived from commercial fertilizers. Abnormally high-nitrate content has also been noted in water from wells as deep as 300 to 650 feet. These wells are all in T. 10 N., R. 25 W., and are perforated in the very permeable alluvial deposits.

ARTIFICIAL RECHARGE

If water were imported to the Cuyama Valley from a source such as the California Aqueduct, the ground-water body could be recharged artificially by constructing spreading basins in many areas. For example, almost anywhere in the central part of the valley in T. 10 N., R. 25 W., recharge could be induced through spreading basins. The water-level contours (fig. 5) indicate that if water were introduced into the Cuyama River at a point just north of Santa Barbara Canyon, it would recharge the basin in the area of greatest storage depletion. Because the water would be introduced into the deepest part of the pumping depression, no water would be lost to the phreatophytes downvalley. A recharge rate of several feet per day probably could be achieved in this area where no significant clay occurs and where the deposits are permeable both vertically and horizontally.

Other areas exist where recharge would be possible, principally along the stream channels near Ozena and along the front of the Sierra Madre Mountains. However, these areas have not had as great a water-level decline as has occurred in T. 10 N., R. 25 W., the deposits are not so permeable, and the storage capacity is not so large.

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